New Source of Evidence: Explosive Traces in Hair

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ABSTRACT

This study examines the sorption of explosives [TNT, RDX, PETN, TATP] to hair during exposure to their vapors. In each test, three colors of hair were simultaneously exposed to explosive vapor. Washing, extracting, and gas chromatographic quantification protocols were developed, and replication of quantitative data was confirmed. Results show that sorption of explosives, via vapor diffusion, to black hair is significantly greater than to blond, brown or bleached hair. Furthermore, the rate of sorption is directly related to the vapor density of the explosive: TATP >>> TNT >> PETN > RDX. Using TNT as the prototype, persistence of the explosive upon standing in air and upon repeated washing with sodium dodecyl sulfate was demonstrated. This study indicates that hair can be a useful indicator of explosive exposure/handling. Work is in progress to develop this technique into an effective forensic tool.

Keywords: TNT, RDX, PETN, TATP, hair, explosive sorption, explosive vapor

1. INTRODUCTION

Hair acts as a solid-phase extraction material, picking up substrates directly by environmental exposure and as a result of ingestion and metabolic activity. Hair mirrors its chemical environment.[1] Since the mid-1900's researchers have been examining hair of laboratory animals and humans as evidence of exposure to chemicals.[2-5] Hair has been shown to sorb heavy metals, pesticides, drugs (illicit and prescription), nicotine, and other chemicals which contaminate the environment (Table 1), but illicit drug detection appears to generate the most interest. While analysis of body fluids, i.e. blood and urine, provide unequivocal evidence of drugs, these methods are invasive. Furthermore, the elimination time is short; abstinence of only a few days reduces concentrations of drugs and their metabolites in body fluids to below detectable limits. In contrast, hair has been shown to retain drugs and their metabolites for many weeks following abstinence. The Society for Forensic Toxicology has accepted drug analysis of hair as a confirmatory technique, and the Substance Abuse and Mental Health Administration reviewed various factors pertinent to use of this technique as legal evidence.[6,7]

Hair testing has the advantages of being non-invasive, having the ability to provide a historical record of exposure, being resistant to countermeasures, and frequently offering a wider window of detection than analysis of body fluids.[8-10] For example, applicants for re-instatement of a drivers license in the province of Brescia, Italy may be required to submit hair samples as proof of sustained abstinence from cocaine and heroin.[11] Despite the advantages, there remains much controversy in using hair as evidence of drug use. Drugs may be incorporated into hair by passive exposure of hair to drugs rather than by illicit use.[8] There is also evidence of color[12-15] (possible racial)[16] bias, though some disagree.[17] Hair color in humans and laboratory animals (rats and monkeys) appears to influence the extent to which drugs are sorbed, with dark hair picking up more than light hair. This is best illustrated in a study where the subjects (rats) had both black and white hairs. The black hairs picked up significantly more methadone than white.[12]A number of studies have attempted to elucidate the sorption processes associated with the binding of drugs to hair. There is convincing evidence that drug-binding sites are associated with melanin granules, but the importance of other factors, such as hair lipid content, is a matter of some debate. One hypothesis is that hydrophobic interactions involving lipids bind non-polar organic substrates to hair. [18-21]

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Table 1

Chemical Substances
amphetamines
barbiturates
benzphetamine & its metabolites
cannabinoids
cocaine, benzoylecgonine & other metabolites
codeine & acetylcodeine
DDT
dextropropoxyphene & norpropoxyphene
diazepam
ephedrine
heroin
Malaoxon
Malathion
methadone and its metabolites
methylenedioxymethylamphetamine (Ecstasy)
morphine & acetylmorphine
nicotine
nordiazepam
ofloxacin
oxazepam
pentobarbital
phencyclidine (PCP)

While the question of environmental exposure versus ingestion remains a point of contention for proof of drug use, this would not be an issue when using hair as evidence of passive exposure. There are many chemicals for which "no exposure" is acceptable. This is the case with most explosives; the majority of citizens should experience "no exposure." Using hair as evidence of exposure to explosives was pioneered by Wardleworth and Ancient of the United Kingdom (RARDE lab, now dstl). They showed that nitrobenzene and ethylene glycol dinitrate (EGDN), both liquids with high vapor pressures, sorbed to bulk hair.[22] With researchers at Defence Scientific Testing Laboratory (dstl), we initiated a preliminary study to evaluate the feasibility of detecting common military explosives in hair. Most military explosives are solids with very low vapor pressures. That study showed that both 2,4-dinitrotoluene and 2,4,6-trinitrotoluene (TNT, the most common filler of landmines) were readily sorbed by hair.[23]

The contamination of hair with explosives can occur by several modes—the interaction of hair with explosive vapor, direct contact of hair with explosive particles, or secondary contact involving direct transfer of particles from hands to the hair. The study reported herein examined contamination of hair via vapor interaction only. This mode of exposure was chosen as a benchmark because it could be performed without the use of human subjects. Cut hair could be acquired by purchase or donation. A complimentary study is underway at dstl to examine particulate transfer to scalp hair of human subjects (The presence of explosive contamination is assessed by swabbing the hair with combs threaded with specially prepared gauze or cotton.). To examine explosive transfer to hair by vapor contact only, weighed quantities of hair were suspended over explosive powder. Four colors of hair were examined—black, brown, blond and bleached—though the majority of the studies focus on the first three. Four organic explosives were used—TNT; hexahydro-1,3,5-trinitro-s-triazine (RDX, the active ingredient in C4); pentaerythritol tetranitrate (PETN, the explosive found in detonating cord and sheet explosives); and triacetone triperoxide (TATP, a homemade explosive recently figuring in a number of terrorist incidents). These explosives represent a broad range of volatilities, (in fact, the vapor density of TATP was measured to confirm this). The sorption isotherm of TNT on the different colored hairs is reported. In addition, the persistence of explosive contamination on hair over time and after treatment with detergent was examined using TNT as the exemplar explosive.

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2. EXPERIMENTAL SECTION

2.1 Exposure of Hair to Explosives

Clear-glass, wide-mouth, screw-cap jars (10.5 cm diameter x 8.5 cm high) were washed with soap and water, rinsed with acetone, oven dried, and cooled to room temperature in a desiccator. Approximately, 0.5 g of explosive was placed in the bottom of the jar. Hair tresses obtained from various sources were washed by repeated rinsing with sodium dodecylsulfate. Each type of hair was removed from its plastic storage bag with forceps, placed on clean paper, and cut into about 1.5-2.5 cm lengths with scissors. About 100 strands of this hair (~0.3 g) were positioned on weighing paper (ends folded), weighed, and transferred into an aluminum foil basket. (The basket was a round aluminum weighing boat 1.5 cm in height and 6 cm in diameter.) Three of these baskets were strung vertically on an aluminum wire so that they would stack into the wide-mouth jar one above the other. Generally, the oriental hair was in the top basket; the brown hair in the middle; and the blond hair in the bottom. As the tier of three baskets was placed into the jar and lid screwed in place, care was taken that no contact was made between hair and other objects, particularly contact with the solid explosive on the bottom of the jar. In initial studies the jars were stored in a fume hood in the laboratory. In later studies, the jars were stored inside a regular cupboard to prevent light from discoloring the explosive. The tier of baskets was removed at various time intervals from 24 to 6000 hours. To determine whether ordering of the hair in the baskets made a difference, blond hair was placed in all three baskets and exposed to TATP for 24 hr. Results were similar to within experimental error (Table 2).

Table 2

Blond Hair Exposed to TATP 24 hr

	ug/g hair	average ug	std dev
Top	47.8		
Top	59.6		
Top	69.7	59.0	10.9
Middle	51.9		
Middle	47.4		
Middle	42.3	47.2	4.8
Bottom	49.6		
Bottom	51.0		
Bottom	60.4	53.7	5.9

Four explosives, all pure powders, were used: 2,4,6-trinitrotoluene (TNT); pentaerythritol tetranitrate (PETN); hexahydro-1,3,5-trinitro-s-triazine (RDX); and triacetone triperoxide (TATP). The amount of explosive sorbed by the hair during this time period was evaluated by extraction with acetonitrile and chromatographic analysis of the extract (see below). To determine whether the amount of hair in each basket affected the results, two exposure chambers were prepared in which each basket contained only a third as much hair (about 0.1 g) as was usually used. The results were identical to each other, indicating reproducibility, and comparable to hair exposed in 0.3 g portions for comparable periods of time.

2.2 Quantification of Explosives Sorbed to Hair

At the completion of the exposure time, the tier of baskets was removed from the TNT-exposure jar, and each hair type was placed on clean waxed paper where it was spread out and fluffed to mix inside and outside tresses. Each type of hair was then divided into three portions of about 0.1 g each. Each portion, three for each of the three hair colors, was weighed into an amber, 16 mL, screw-cap bottle. None of the hair strands was allowed to touch the lid of the bottle. Acetonitrile (5.00 mL) was added, and the samples were sonicated for 20 minutes before they were placed on a shaker (speed 86 shakes/minute) for overnight extraction. After extraction was deemed complete, the acetonitrile was removed using a Pasteur pipette and about 1 mL of this solution was put in a 2 mL, septum screw-cap vial (Initially, the acetonitrile solution was filtered prior to placement in gas chromatographic (GC) vials; however, this step was later

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eliminated as unnecessary.) The acetonitrile extracts were analyzed on a Hewlett Packard (HP) 5890 gas chromatograph (GC) or an Agilent 6890N using an electron capture detector (ECD). The column used was a J&W Scientific DB-5MS column [8 m x 0.53mm (megabore), film 1.5 um] (HP) or a HP-5 (20 m x 0.25mm, capillary column, Agilent). Details, including the injector and detector temperatures, initial and final oven temperature, hold times and ramp rates, are shown below in Table 3. An external standard method was used to quantify samples. Standard curves were constructed (using 5 points between 0.01 and 1.0 ppm) based on peak height and peak area. The squared correlation coefficients for the standard curves were better than 0.99. Both height and area data gave comparable results.

Table 3: GC Analysis Conditions

Sample	split/ splitless	Sample Volume (uL)	Injector Temperture (°C)	Detector Temperture (°C)	Oven Temperture (°C)	Hold Time (sec)	Ramp Rate (deg/min)	Final Temperature (°C)	Final Hold Time (min)	Retention Time (min)
PETN hair	split 5:1	1	175	250	50	60	20	200	5	7.7
RDX hair	split 12.5:1	1	195	320	50	60	10 to 200C, 20	250	5	15.5
TATP hair	split 125:1	1	165	300	50	120	20	220	0.5	5.5
TATP vapor@	split 125:1	10	165	300	50	120	20	280	2	6
TNT vapor@	split 5:1	10	165	300	50	120	20	280	2	10
TNT hair*	splitless	1	175	325	60	30	15	200	10	7

* Analyses performed on HP 5890 GC with DB-5MS column; all others used Agilent 6890N with HP-5 column.

3. RESULTS AND DISCUSSION

Because there were many reports that hair color affected drug uptake, our initial studies used black, blond and bleached hair. We found, as had been reported for drugs, that the black hair picked up more chemical (in this case, TNT) than blond and that bleached hair picked up little TNT. (Fig. 1) Thus, for the majority of the study, brown hair, rather than bleached was used.

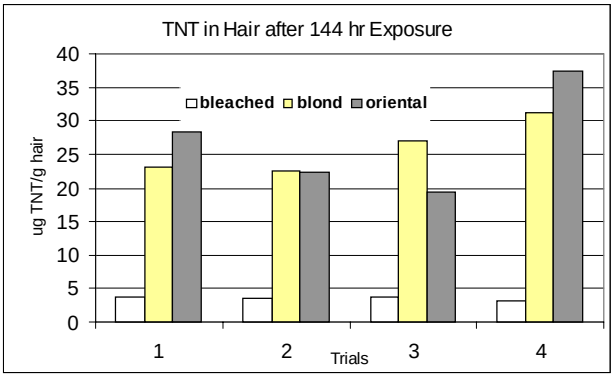

Fig. 1. TNT uptake by hair

Three colors of hair, black (oriental), brown, and blond were exposed to TNT vapors for varying amounts of time in an attempt to determine at what concentration the hair was saturated. Table 4 shows the micrograms of TNT observed on average of three runs for 10 time intervals. When this data is plotted (Fig. 2), it appears that the hair may be nearing saturation at 1800 hours (75d), but longer time studies are underway. For the brown and blond hair, sorption of TNT reached a maximum at ~50 and 60 ug/g hair, respectively, after about 500 hours. In contrast, black, oriental hair picked up greater than 100 ug of TNT per gram hair and was still sorbing more after 1000 hours.

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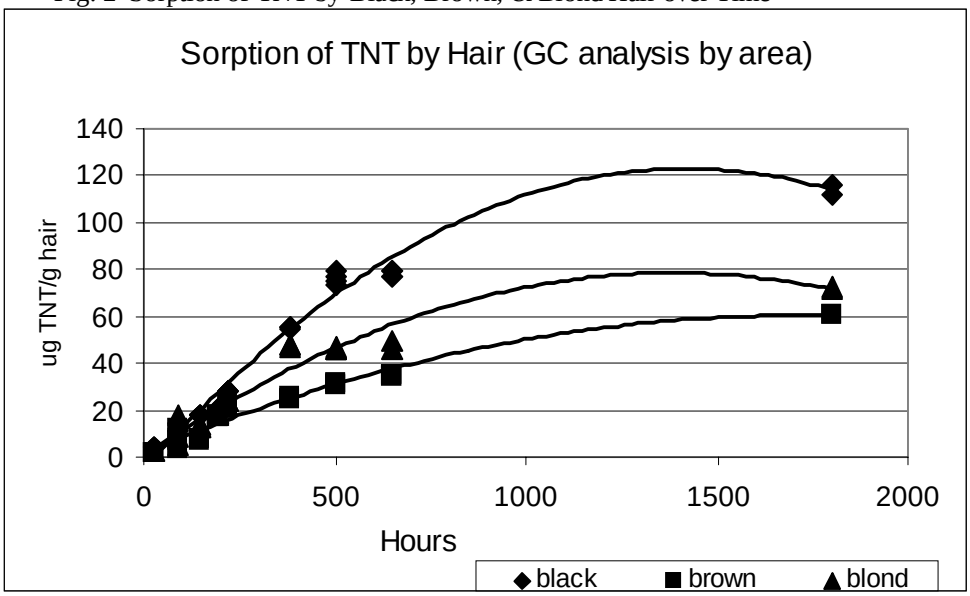
Table 4

TNT Sorbed to Hair ug TNT/g Hair (GC Analysis by area)

hair\ hours	24	91	144	192	220	380	500	504	648	1800
oriental	4.2	13	18	20	28	55	80	75	79	114
brown	1.4	7.2	7.4	17	21	25	32	31	34	61
blond	2.4	10	13	19	24	48	46	47	48	72
bleached			3.6							

Fig. 2 Sorption of TNT by Black, Brown, & Blond Hair over Time



Much longer exposure times were needed before significant quantities of PETN or RDX were sorbed. The results are shown in Tables 5 and 6. After 5040 hr the amount of PETN sorbed by black, blond and brown hair was about the same as the maximum observed for TNT—100 ug, 60 ug, and 50 ug per gram hair, respectively. Although without longer-term studies, it is impossible to know whether more PETN would be sorbed, this coincidence suggested that perhaps hair had a limited number of binding sites for nitro compounds but that the rate of explosive uptake was related to the vapor pressure of the explosive. Both these hypotheses could be probed by use of another explosive of completely different chemical type—TATP. Results shown in Table 6 show that, indeed, the affinity of hair for this chemical is totally different from that for TNT or PETN. However, this does not necessarily support the hypothesis of a set number of binding sites for nitro-containing compounds.

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Table 5

PETN (ug)/g Hair

hair\ hours	1848	2376	5040
oriental 1	60	100	103
oriental 2	59	97	103
brown 1	24	37	59
brown 2	24	37	60
blond 1	34	38	75
blond 2	36	39	75

Table 6

RDX (ug)/g Hair

hair/hours	768h	5808 h
oriental	5.6	7.6
oriental	5.6	7.1
brown	1.6	2.1
brown	1.6	2.3
blond	2.0	2.6
blond	2.0	2.7

3.1 Similar Uptake Maxima

Table 5 indicates that at 5040 hours (~7 months) micrograms of PETN sorbed approached the same levels observed for the three colors of hair for TNT after 75 days. The hypothesis was that saturation levels of hair were the same for every explosive, but the rates of achieving saturation were dramatically different. To test this, a different type of explosive was used—TATP. The uptake of TATP was prompt and dramatic. The plateau ~100 ug/g black hair is not observed for TATP (Table 7). One could still postulate that the plateau exists for NO_2 functionalized explosives. (An in-progress examination of EGDN will settle that question.)

Table 7

TATP (ug)/g Hair

hair\ hours	48	240
oriental 1	1061	1673
oriental 2	1080	1681
oriental 2	1096	
brown 1	38	92
brown 2	37	84
brown 3	38	
blond 1	58	199
blond 2	55	201
blond 3	53	

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3.2 Sorption Directly Related to Vapor Pressure

Vapor pressure data were available for TNT, RDX, and PETN, but none had been reported for TATP. Therefore, the first step to answering this question was to determine the vapor pressure of TATP. The vapor density of TATP in sealed containers, equilibrated at specified temperatures, was determined by injecting known volumes of vapor into a gas chromatograph with electron capture detection. Assuming ideal gas behavior, it was possible to calculate the vapor pressure. Vapor pressures were measured as a function of temperature and a Clapeyron plot, constructed. Details have been reported elsewhere.[24] The vapor density of TNT was measured at the same time to confirm the applicability of the protocol used to determine the vapor pressure of TATP. The value determined for TNT was in good agreement with those reported in the literature (Table 8). Thus, we have confidence in the value measured for TATP--0.03 mm at 25°C.

Table 8

Values for TNT & TATP Vapor Pressure				
$\log_{10}P(mmHg) = A-[B/T(K)]$				
A	B	mm Hg at 25°C	ΔH_{sub} (kJ/mol)	References
--	--	5.80E-06	--	Hobbs, 1986
12.31	5175	8.79E-06	--	Pella, 1977
19.23	7371	3.08E-06	--	Leggett, 1977
15.43	6180	4.92E-06	118	Edwards, 1950
12.6	5900	5.61E-06	113	Cundall, 1978
8.754	4227	3.94E-06	81	TNT--Oxley et al
17.666	5708	3.25E-02	109	TATP--Oxley et al

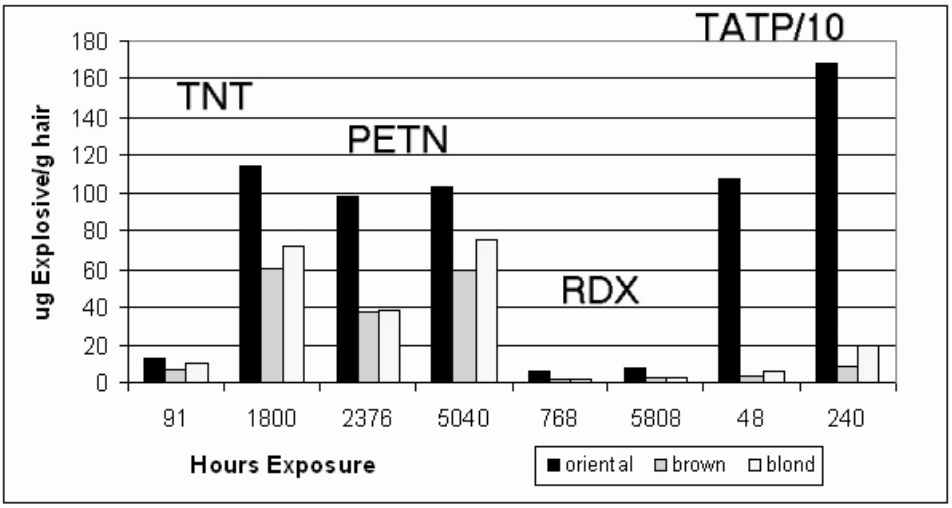

Fig. 3. Sorption of Various Explosives vs. Time (TATP values were divided by 10)

Figure 3 illustrates explosive uptake of the various explosives. Table 9 gives estimated rates of explosive sorption. It was constructed by simply dividing the micrograms of explosive sorbed by the shortest time studied. Though the values,

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thus obtained, cannot be considered true rates, they provide a rough comparison of rates and show that rate of sorption is directly correlated with vapor density. Thus, the rate at which each explosive is sorbed appears related to its vapor density.

. TATP(**0.03**) >>> TNT(**4×10^{-6}**) >> PETN(**2×10^{-8}**) > RDX(**2×10^{-9}**)

Table 9

ug explosive/hour exposure

	TATP	TNT	PETN	RDX
oriental	22	0.18	0.03	0.007
brown	0.79	0.06	0.01	0.001
blond	1.10	0.10	0.02	0.003
torr	3.0E-02	4.0E-06	2.0E-08	2.0E-09

3.3 Persistence of TNT in Hair

Experiments described above showed that hair sorbed explosive vapor. The important questions were did it retain this vapor and under what conditions. These questions were examined using TNT-exposed hair. Hair exposed to TNT for 648 hours and 1800 hours was divided into three portions (~0.1 g each). One portion of each hair type was placed on a clean watch glass in an explosive-free location (an office), physically separated from the laboratory for about 2 days and 6 days, respectively. These portions of hair along with the other two portions of each hair type were analyzed by above procedures. No loss of TNT was apparent (Table 10).

Table 10

Persistance of TNT on Hair upon Standing

Hours Hair Exposed to TNT	Hair color	ug/g hair	Hair color	ug/g hair	Hair color	ug/g hair	
648	oriental	77	brown	35	blond	49	freshly prepared
648	oriental	79	brown	34	blond	46	freshly prepared
648	oriental	79	brown	34	blond	48	exposed to air 2 days
% TNT Remaining		**103%**		**98%**		**97%**	**2 days in air**
1800	oriental	116	brown	61	blond	72	freshly prepared
1800	oriental	112	brown	61	blond	72	freshly prepared
1800	oriental	105	brown	55	blond	66	exposed to air 6 days
1800	oriental	103	brown	57	blond	64	exposed to air 6 days
% TNT Remaining		**91%**		**92%**		**90%**	**6 days in air**

The persistence of TNT upon washing of hair with detergent was evaluated. Two of the three 0.1 g portions of the hair exposed to TNT 500 hours were washed with sodium dodecylsulfate (SDS) solution as given below. The remaining portion of hair was analyzed (as described above) without washing. The washing process involved placing 0.1 g portions of hair in 100 mL beakers with ~0.5 mL of 2 % SDS solution. The mixture was stirred well with a glass rod. After a little water (~5 mL) was added, the foam was decanted, and the procedure was repeated. The hair was then rinsed three times until no foam was visible. The hair was dried on weighing paper with paper towel underneath for about two hours on a laboratory bench. Once dry, hair was extracted with acetonitrile as described above. These tests were repeated using hair that had been exposed to TNT 1800 hours and with 6 rinsings with SDS solution. Results of these tests are shown in Table 11 along with the results of a similar study using hair that had been exposed to PETN for 5040 hours. The hair lost 30% to 60% of the sorbed TNT in the 3-rinse protocol and over 90% of the TNT in the 6-rinse protocol. Washing of hair exposed to PETN (5040 hr) showed up to 98% loss, yet some PETN persisted.

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Table 11

Persistance of TNT on Hair upon Standing

Hours Hair Exposed to TNT	Hair color	ug/g hair	Hair color	ug/g hair	Hair color	ug/g hair	
500	oriental	80	brown	32	blond	46	freshly prepared
500	oriental	31	brown	22	blond	20	3 rinses with SDS
500	oriental	32	brown	22	blond	20	3 rinses with SDS
% TNT Remaining		**40%**		**69%**		**43%**	**3 rinses**
1800	oriental	116	brown	61	blond	72	freshly prepared
1800	oriental	112	brown	61	blond	72	freshly prepared
1800	oriental	23	brown	5	blond	6	6 rinses with SDS
1800	oriental	24	brown	5	blond	6	6 rinses with SDS
% TNT Remaining		**20%**		**8%**		**8%**	**6 rinses**
Hours Hair Exposed to PETN	Hair color	ug/g hair	Hair color	ug/g hair	Hair color	ug/g hair	
5040	oriental	103	brown	59	blond	75	freshly prepared
5040	oriental	103	brown	60	blond	75	freshly prepared
5040	oriental	4.4	brown	1.4	blond	1.6	3 rinses with SDS
5040	oriental	5.7	brown	1.4	blond	1.7	3 rinses with SDS
% PETN Remaining		**5%**		**2%**		**2%**	**3 rinses**

4. CONCLUSIONS

This study demonstrates the viability of hair as a surface from which explosive traces can be recovered. While contamination of hair may come by contact of the subjects' hair with explosive vapor or by particulate transfer—direct or indirect (e.g. hands transfer to hair), this study specifically examined the vapor transfer. It showed that even explosives with extremely low vapor pressure (i.e. RDX) may be sorbed by hair. Furthermore, preliminary results from the British Defence Scientific and Technical Laboratory (dstl) Forensic Explosive Laboratory suggest that particulate transport is more significant.

The sorbed explosive persists. Simply standing in air, TNT remained on hair up to six days. (Six days was the maximum standing time allowed since it was assumed after six days, head hair would be washed.) It is likely that similar persistence in air will be observed for PETN and RDX. For the highly volatile TATP this may not be true, and studies are underway to determine its persistence upon standing. A more rigorous test of persistence is washing. Though explosive sorbed by hair was susceptible to removal during washing, laboratory washings showed that some explosives persists through up to six rinses. Since frequency and mode of hair washing varies dramatically among individuals, there is the possibility that explosive residues will persist in hair for days after exposure. Indeed, preliminary tests by dstl showed that some workers, who reportedly washed their hair after a day of exposure to explosives, were still found contaminated the following day. Although many issues need to be resolved, this study showed the feasibility of using hair as forensic evidence of explosive handling.

REFERENCES

1."Measuring and Monitoring the Environment," J. Lenihan & W.W. Fletchers, Ed; Academic Press, NY 1978, pp66-86.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 07/09/2016 Terms of Use: http://spiedigitallibrary.org/ss/TermsOfUse.aspx

2. Goldblum, R.W.; Goldbaum, L.R., Piper, W.N. "Barbiturate concentrations in the skin and hair of guinea pigs" *J. Invest. Dem.* **1954**, 22, 121-128.
3. Pehl, R.O.; Parkes, M. "Hair analysis on learning and behaviour problems. Hair Trace Elements & Human Illness. A.C. Brown & R. Crouse, Ed. Prager Pub. NY 1980; pp 138-143.
4. Drug Testing in Hair, Kintz, P., ed. ; CRC Press, NY, 1996
5. Deanna Leigh Hubbard "Hair as a matrix for biomarkers of pesticide exposure" Dept. Pharmacology & Toxicology; U of Utah, PhD thesis, Dec 2001.
6. Society for Forensic Toxicology (SOFT), Consensus statement, 1990, 1992.
7. Substance Abuse and Mental Health Administration of the U.S. Dept. of Health & Human Services, "Factors Required for Reliable Workplace Drug Testing, Aug. 1998.
8. Dupont R.L.; Baumgartner W.A. "Drug testing by urine and hair analysis: complementary features and scientific issues" *Forensic Sci Int.***1995**; 70(1-3): 63-76.
9. Kintz P, Mangin P. "Evidence of gestational heroin or nicotine exposure by analysis of fetal hair" *Forensic Sci Int*. 1993; 63(1-3): 99-104
10. Kelly KS, Rogers R. "Detection of misreported drug use in forensic populations: an overview of hair Analysis" *Bull Am Acad Psychiatry Law* **1996**; 24(1): 85-94.
11. Ricossa, M.C.; Bernini, M.; DE Ferrari, F. Hair analysis for driving license in cocaine and heroin users. An epidemiological study. *Forensic Sci Int.* **2000** ; 107, (1-3): 301-8.
12. Green S.J.; Wilson, J. F." The effect of hair color on the incorporation of methadone into hair in the rat." J Anal Toxicol 1996, 20, (2), 121-3.
13. Borges, C.R.; Wilkins, D.G.; Rollins, D.E. "Amphetamine and N-acetylamphetamine incorporation into hair: an investigation of the potential role of drug basicity in hair color bias." *J Anal Toxicol* **2001**, *25(4),* 221-7
14. Rollins, D.E.; Wilkins, D.G.; Krueger, G.G.; Augsburger, M.P.; Mizuno, A.; O'Neal, C; Borges, C.R.; Slawson, M.H."The effect of hair color on the incorporation of codeine into human hair." *J Anal Toxicol* **2003**, *27(8),* 545-51
15. Ursitti, F.; Klein, J; Sellers, E.; Koren, G. Use of hair analysis for confirmation of self-reported cocaine use in users with negative urine tests. *J Toxicol Clin Toxicol.* 2001; 39, (4): 361-6.
16. Henderson, G.L.; Harkey, M.R.; Zhou, C.; Jones, R.T.; Jacob P 3rd. "Incorporation of Isotopically Labeled Cocaine and Metabolites into Human Hair: 1. Dose-Response Relationships." *J Anal Toxicol*. **1996** ; *20(1):* 1-12.
17. Kelly, R.C.; Mieczkowski, T., Sweeney, S.A.; Bourland, J.A. "Hair analysis for drugs of abuse. hair color and race differentials or systematic differences in drug preferences?" *Forensic Sci Int* **2000**, *107, (1-3),* 63-86.
18. Potsch, L.; Skopp, G.; Rippin, G. "A comparison of 3H-cocaine binding on melanin granules and human hair in vitro." *Int J Legal Med* **1997,** *110(2),* 55-62.
19. Potsch, L.; Skopp, G.; Moeller, M.R." Biochemical approach on the conservation of drug molecules during hair fiber formation. "*Forensic Sci Int* **1997,** 17, *(84(1-3)),* 25-35.
20. Slawson, M.H.; Wilkins, D.G.; Rollins, D.E. "The incorporation of drugs into hair: relationship of hair color and melanin concentration to phencyclidine incorporation," *J Anal Toxicol* **1998,** *22 (6),* 406-13.
21. Uematsu T, Miyazawa. N., Okazaki O, Nakashima M., Possible effect of pigment on the pharmacokinetics of ofloxacin and its excretion in hair. *J Pharm Sci* **1992,** 81, (1)
21. Joseph, R.E. Jr; Su, T.P.; Cone, E.J. "In vitro binding studies of drugs to hair: influence of melanin and lipids on cocaine binding to Caucasoid and Africoid hair." *J Anal Toxicol* 1996, 20, (6), 338-44.
22. D.F. Wardleworth, D.F.; Ancient, S.A. "The Sorption of Explosives on Human Hair" Proc. Int. Symp. Analysis & Detection of Explosives; F.B.I., Washington D.C 1983.
23. Marshall, M; Sanders, K.; Oxley, J.; Smith, J.; Egee, L. "Explosive Recovery from Hair" *Science & Justice* **2002**, *42(3),* 137-142.
24. Oxley, J. C., Smith, J.L., Shinde, K., Moran, J. Determination of the Vapor Density of Triacetone Triperoxide submitted to *Propellants Explosive & Pyrotechnics.*

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